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13. A sledge hammer is used to drive a wedge into a log to split it. When the wedge is driven 20 cm into the log, the log is separated a distance of 5.0 cm. A force of 1.9 x 10^4 N is needed to split the log, and the sledge exerts a force of 9.8 × 10^3 N.

a. What is the *IMA* of the wedge?

$$IMA = \frac{d_e}{d_r} = \frac{20\text{ cm}}{5.0\text{ cm}} = 4.0$$

b. Find the *MA* of the wedge.

$$MA = \frac{F_r}{F_e} = \frac{1.9 \times 10^4\text{ N}}{9.8 \times 10^3\text{ N}} = 1.9$$

c. Calculate the efficiency of the wedge as a machine.

$$Efficiency = \left[\frac{MA}{IMA}\right] \times 100\%$$

$$= \left[\frac{1.9}{4.0}\right] \times 100\% = 48\%$$

14. A worker uses a pulley system to raise a 225–N carton 16.5 m. A force of 129 N is exerted and the rope is pulled 33.0 m.

a. What is the mechanical advantage of the pulley system?

$$MA = \frac{F_r}{F_e} = \frac{225\text{ N}}{129\text{ N}} = 1.74$$

b. What is the efficiency of the system?

$$Efficiency = \left[\frac{MA}{IMA}\right] \times 100\%, \text{ where}$$

$$IMA = \frac{d_e}{d_r} = \frac{33.0\text{ m}}{16.5\text{ m}} = 2.00, \text{ so}$$

$$Efficiency = \frac{1.74}{2.00} \times 100\% = 87\%$$

15. A boy exerts a force of 225 N on a lever to raise a 1.25 × 10^3–N rock a distance of 0.13 m. If the efficiency of the lever is 88.7%, how far did the boy move his end of the lever?

$$eff = \frac{W_o}{W_i} \times 100\% = \frac{F_r d_r}{F_e d_e} \times 100\%, \text{ so}$$

$$d = \frac{F_r d_r (100\%)}{F_e (eff)}$$

$$= \frac{(125 \times 10^3\text{ N})(0.13\text{ m})(100\%)}{(225\text{ N})(88.7\%)}$$

$$= 0.81\text{ m}$$

16. If the gear radius is doubled in the example above, while the force exerted on the chain and the distance the wheel rim moves remain the same, what quantities change, and by how much?

$$IMA = \frac{8.00\text{ cm}}{35.6\text{ cm}} = 0.224$$

$$MA = (95\%)\frac{0.224}{100\%} = 0.214 \text{ (both doubled)}$$

The force exerted by the distance the chain moved, d_e, would also be doubled to 3.14 cm.

Chapter Review Problems

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1. Lee pushes horizontally with an 80–N force on a 20–kg mass 10 m across the floor. Calculate the amount of work Lee did.

$W = Fd = (80\text{ N})(10\text{ m}) = 800\text{ J}.$
The mass is not important to this problem.

2. The third floor of a house is 8.0 m above street level. How much work is needed to move a 150–kg refrigerator to the third floor?

$F = mg$, so
$W = Fd = mgd = (150\text{ kg})(9.8\text{ m/s}^2)(8.0\text{ m})$

3. Stan does 176 J of work lifting himself 0.300 m. What is Stan's mass?

$F = mg$, so $W = Fd = mgd$; therefore,

$$m = \frac{W}{gd} = \frac{176\ \text{J}}{(9.80\ \text{m/s}^2)(0.300\ \text{m})} = 59.9\ \text{kg}$$

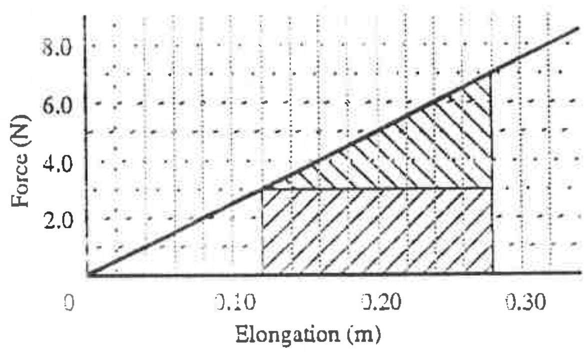
4. A crane lifts a 2.25×10^3-N bucket containing $1.15\ \text{m}^3$ of soil (density = $2.00 \times 10^3\ \text{kg/m}^3$) to a height of 7.50 m. Calculate the work the crane performs.

$W = Fd$, where F is the weight of bucket plus soil. The soil mass is
$(1.15\text{m}^3)(2.00 \times 10^3\ \text{kg/m}^3) = 2.30 \times 10^3$ kg.
The bucket's weight is 2.25×10^4 N, so the total weight is 2.48×10^4 N. Thus,
$W = Fd = (2.48 \times 10^4\ \text{N})(7.50\ \text{m})$
$= 1.86 \times 10^5$ J.

5. The graph in Figure 10–16 shows the force needed to stretch a spring. Find the work needed to stretch it from 0.12 m to 0.28 m.

Add the areas of the triangle and rectangle. The area of the triangle is
(base)(height)/2 = (0.16 m)(4.0 N)/2 = 0.32 J.
The area of the rectangle is
(base)(height) = (0.16 m)(3.0 N) = 0.48 J.
Total work is 0.32 J + 0.48 J = 0.80 J.

6. In Figure 10–10 the magnitude of the force necessary to stretch a spring is plotted against the distance the spring is stretched.



Chapter Review Problems

a. Calculate the slope of the graph and show that

$$F = kd$$

where k = 25 N/m.

$$m = \frac{\Delta_y}{\Delta_x} = \frac{(5.0\ \text{N} - 0.0\ \text{N})}{(0.20\ \text{m} - 0.00\ \text{m})}$$

$$= \frac{5.0\ \text{N}}{0.20\ \text{m}} = 25\ \text{N/m}$$

$F = kd = (25\ \text{N/m})(0.20\ \text{m}) = 5.0$ N

b. Find the amount of work done in stretching the spring from 0.00 m to 0.20 m by calculating the area under the curve from 0.00 m to 0.20 m in Figure 10–10.

$$A = \frac{1}{2}(\text{base})(\text{height}) = \left[\frac{1}{2}\right](5.0\ \text{N})(0.20\ \text{m})$$

$$= 0.50\ \text{J}$$

c. Show that the answer to part b can be calculated using the formula

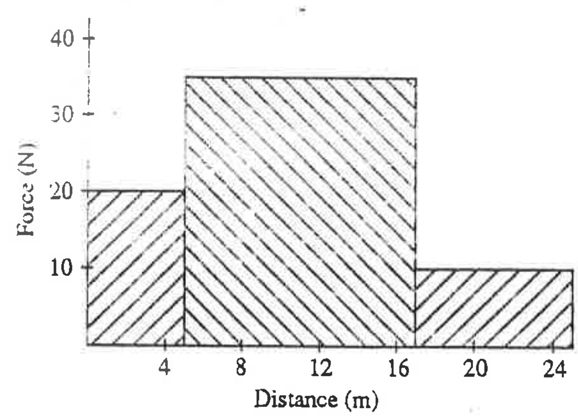
$$W = \frac{1}{2}kd^2$$

where W is the work, k = 25 N/m (the slope of the graph), and d is the distance the spring is stretched (0.20 m).

$$W = \frac{1}{2}kd^2 = \left[\frac{1}{2}\right](25\ \text{N/m})(0.20\ \text{m})^2 = 0.50\ \text{J}$$

7. John pushes a crate across the floor of a factory with a horizontal force. The roughness of the floor changes, and John must exert a force of 20 N for 5 meters, then 35 N for 12 m, then 10 N for 8 m.

a. Draw a graph of force as a function of distance.



b. Find the work John does pushing the crate.

Add the areas under the rectangles
(5 m)(20N) + (12 m)(35 N) + (8 m)(10 N)
= 100 J + 420 J + 80 J = 600 J.

8. Sally applies a horizontal force of 462 N with a rope to drag a wooden crate across a floor with a constant speed. The rope tied to the crate is pulled at an angle of 56.0°.

a. How much force is exerted by the rope on the crate?

462 N is the horizontal component, so the force is $\dfrac{462\text{ N}}{\cos 56.0°} = 826$ N.

b. What work is done by Sally if the crate is moved 24.5 m?

$W = Fd = (462\text{ N})(24.5\text{ m}) = 1.13 \times 10^4$ J.

c. What work is done by the floor through force of friction between the floor and the crate?

Force and displacement are in opposite directions, so
$W = -(462\text{ N})(24.5\text{ m}) = -1.13 \times 10^4$ J.

9. Mike pulls a sled across level snow with a force of 225 N along a rope that is 35.0° above the horizontal. If the sled moved a distance of 65.3 m, how much work did Mike do?

$W = Fd\cos\theta = (225\text{ N})(65.3\text{ m})\cos 35.0°$
$= 1.20 \times 10^4$ J.

10. An 845-N sled is pulled a distance of 185 m. The task requires 1.20×10^4 J of work and is done by pulling on a rope with a force of 125 N. At what angle is the rope held?

$W = Fd\cos\theta$, so

$$\cos\theta = \frac{W}{Fd} = \frac{(1.20 \times 10^4\text{ J})}{(125\text{ N})(185\text{ m})} = 0.519;$$

therefore, $\theta = 58.7°$.

11. Karen has a mass of 57.0 kg and rides the up escalator at Woodley Park Station of the Washington D.C. Metro. Karen rode a distance of 65 m, the longest escalator in the free world. How much work did the escalator do on Karen if it has an inclination of 30°?

$W = Fd$ but $F = mg$, so
$W = mgd$
$= (57.0\text{ kg})(9.80\text{ m/s}^2)(65\text{ m})\sin 30°$
$= 1.8 \times 10^4$ J.

12. Chris carried a carton of milk, weight 10.0 N, along a level hall to the kitchen, a distance of 3.50 m. How much work did Chris do?

No work because the force and the displacement are perpendicular.

13. A student librarian picks up a 22-N book from the floor to a height of 1.25 m. He carries the book 8.0 m to the stacks and places the book on a shelf that is 0.35 m high. How much work does he do on the book?

Only the net vertical displacement counts.
$W = Fd = (22\text{ N})(0.35\text{ m}) = 7.7$ J.

14. Pete slides a crate up a ramp at an angle of 30.0° by exerting a 225-N force parallel to the ramp. The crate moves at a constant speed. The coefficient of friction is 0.28. How much work has been done when the crate is raised a vertical distance of 1.15 m?

To find the distance, d, along the plane from h, the vertical distance

$$d = \frac{h}{\sin 30.0°} = \frac{(1.15\text{ m})}{0.500} = 2.30\text{ m}.$$

F and d are parallel so
$W = Fd = (225\text{ N})(2.30\text{ m}) = 518$ J.

15. A 4200-N piano is to be slid up a 3.5-m frictionless plank that makes an angle of 30.0° with the horizontal. Calculate the work done in sliding the piano up the plank.

The force parallel to the plane is given by $F_{11} = F\sin\theta$, so $W = F_{11}d = Fd\sin\theta$
$W = (4200\text{ N})(3.5\text{ m})(\sin 30.0°) = 7.4 \times 10^3$ J

16. A 60-kg crate is slid up an inclined ramp 2.0 m long onto a platform 1.0 m above floor level. A 400-N force, parallel to the ramp, is needed to slide the crate up the ramp at a constant speed.

a. How much work is done in sliding the crate up the ramp?

$W = Fd = (400 \text{ N})(2.0 \text{ m}) = 800 \text{ J}$

b. How much work would be done if the crate were simply lifted straight up from the floor to the platform?

$W = Fd = mgd = (60 \text{ kg})(9.80 \text{ m/s}^2)(1.0 \text{ m}) = 600 \text{ J}.$

17. Brutus, a champion weightlifter, raises 240 kg a distance of 2.35 m.

a. How much work is done by Brutus lifting the weights?

$W = Fd = mgd$
$= (240 \text{ kg})(9.80 \text{ m/s}^2)(2.35 \text{ m})$
$= 5.53 \times 10^3 \text{ J}$

b. How much work is done holding the weights above his head?

$d = 0$ so no work.

c. How much work is done lowering them back to the ground?

d is opposite of motion in part a, so W is also the opposite, -5.53×10^3 J.

d. Does Brutus do work if the weights are let go and fall back to the ground?

No. He exerts no force, so he does no work, positive or negative.

e. If Brutus completes the lift in 2.5 seconds, how much power is developed?

$P = \frac{W}{t} = (5.53 \times 10^3 \text{ J})/(2.5 \text{ s}) = 2.2 \text{ kW}.$

Chapter Review Problems

18. A force of 300 N is used to push a 145-kg mass 30.0 m horizontally in 3.00 s.

a. Calculate the work done on the mass.

$W = Fd = (300 \text{ N})(30.0 \text{ m}) = 9.00 \times 10^3 \text{ J}$

b. Calculate the power.

$$P = \frac{W}{t} = \frac{9.00 \times 10^3 \text{ J}}{3.00 \text{ s}} = 3.00 \times 10^3 \text{ W}$$
$$= 3.00 \text{ kW}$$

19. Robin pushes a wheelbarrow by exerting a 145-N force horizontally. Robin moves it 60.0 m at a constant speed for 25.0 s.

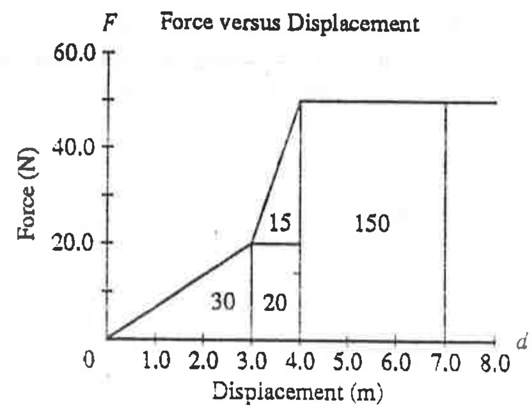
a. What power does Robin develop?

$$P = \frac{W}{t} = \frac{F \cdot d}{t} = \frac{(145 \text{ N})(60.0 \text{ m})}{25.0 \text{ s}} = 348 \text{ W}$$

b. If Robin moves the wheelbarrow twice as fast, how much power is developed?

Either d is doubled or t is halved, so P is doubled to 696 W.

20. a. Use the graph to calculate the work done to pull the object 7.0 m.



Find the area under the curve (see graph):
0 to 3 m;

$\frac{1}{2}(20.0\ N)(3.0\ m) = 30\ J$

3 m to 4 m;

$\frac{1}{2}(30.0\ N)(1.0\ m) + (20\ N)(1.0\ m) = 15\ J + 20\ J = 35\ J$

4 m to 7 m;
$(50.0\ N)(3.0\ m) = 1.5 \times 10^2\ J$

Total work;
$30\ J + 35 J + 1.5 \times 10^2\ J = 2.2 \times 10^2\ J$

b. Calculate the power if the work were done in 2.0 seconds.

$$P = \frac{W}{t} = \frac{2.2 \times 10^2\ J}{2.0\ s} = 1.1 \times 10^2\ W.$$

21. In 35.0 s, a pump delivers 550 dm^3 of oil into barrels on a platform 25.0 m above the pump intake pipe. The density of the oil is 0.820 g/cm^3.

a. Calculate the work done by the pump.

Mass lifted = $(550\ dm^3)(1000\ cm^3/dm^3)(0.820\ g/cm^3) = 4.51 \times 10^5\ g = 451\ kg$

The work done is
$W = F_w d = mg(h) = (451\ kg)(9.80\ m/s^2)(25.0\ m) = 1.10 \times 10^5\ J = 110\ kJ$

b. Calculate the power produced by the pump.

$$P = \frac{W}{t} = \frac{(110\ kJ)}{(35.0\ s)} = 3.14\ kW$$

22. A horizontal force of 805 N is needed to drag a crate across a horizontal floor with a constant speed. Pete drags the crate using a rope held at an angle of 32°.

a. What force does Pete exert on the rope?

$F_x = F \cos \theta$, so

$$F = \frac{F_x}{\cos \theta} = \frac{(805\ N)}{\cos 32°} = 949\ N$$

b. How much work does Pete do on the crate when moving it 22 m?

$W = F_x d = (805\ N)(22\ m) = 1.8 \times 10^4\ J$

c. If Pete completes the job in 8.0 s, what power is developed?

$$P = \frac{W}{t} = \frac{1.8 \times 10^4\ J}{8.0\ s} = 2.3\ kW$$

23. Wayne pulls a 305–N sled along a snowy path using a rope that makes a 45.0° angle with the ground. Wayne pulls with a force of 42.3 N. The sled moves 16 m in 3.0 s. What is Wayne's power?

$$P = \frac{W}{t} = \frac{F_{\parallel}d}{t} = \frac{Fd_{\parallel}}{t}\cos\theta = (42.3\text{ N})(16\text{ m})(\cos 45.0°)/(3.0\text{ s}) = 1.6 \times 10^2\text{ W}$$

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24. A lawn roller is rolled across a lawn by a force of 115 N along the direction of the handle, which is 22.5° above the horizontal. If George develops 64.6 W of power for 90.0 seconds, what distance is the roller pushed?

$$P = \frac{W}{t} = \frac{Fd\cos\theta}{t}$$

$$d = \frac{Pt}{F\cos\theta} = \frac{(64.6\text{ W})(90.0\text{ s})}{(115\text{ N})(\cos 22.5°)} = 54.7\text{ m}$$

25. A 12.0–m long conveyor belt, inclined at 30.0°, is used to transport bundles of newspapers from the mail room up to the cargo bay to be loaded on delivery trucks. Each newspaper has a mass of 1.00 kg and there are 25 newspapers per bundle. Determine the useful power of the conveyor if it delivers 15 bundles per minute.

$$P = \frac{W}{t} = \frac{Fd}{t} = \frac{mgd}{t} = \frac{(25)(15)(1.00\text{ kg})(9.80\text{ m/s}^2)(\sin 30.0°)(12.0\text{ m})}{60.0\text{ s}} = 3.68 \times 10^2\text{ W}$$

26. An engine moves a boat through the water at a constant speed of 15 m/s. The engine must exert a force of 6.0×10^3 N to balance the force that water exerts against the hull. What power does the engine develop?

$$P = \frac{W}{t} = \frac{Fd}{t} = Fv = (6.0 \times 10^3\text{ N})(15\text{ m/s}) = 90\text{ kW}$$

27. A 188–W motor will lift a load at the rate (speed) of 6.50 cm/s. How great a load can the motor lift at this speed?

$v = 6.50\text{ cm/s} = 0.0650\text{ m/s}$

$$P = \frac{W}{t} = \frac{Fd}{t} = F\left[\frac{d}{t}\right] = Fv$$

$$P = F_w v$$

$$F_w = \frac{P}{v} = \frac{(188\text{ W})}{(0.0650\text{ m/s})} = 2.89 \times 10^3\text{ N}$$

28. A car is driven at a constant speed of 21 m/s (76/km/h) down a road. The car's engine delivers 48 kW of power. Calculate the average force of friction that is resisting the motion of the car.

$$P = \frac{W}{t} = \frac{Fd}{t} = Fv\text{, so } F = \frac{P}{v} = \frac{(48{,}000\text{ W})}{(21\text{ m/s})} = 2.3 \times 10^3\text{ N}$$

29. Stan raises a 1000–N piano a distance of 5.00 m using a set of pulleys. Stan pulls in 20.0 m of rope.

a. How much effort did Stan apply if this was an ideal machine?

$F_e d_e = F_r d_r$, so

$$F_e = \frac{F_r d_r}{d_e} = \frac{(1000\ \text{N})(5.00\ \text{m})}{(20.0\ \text{m})} = 250\ \text{N}$$

b. What force is used to overcome friction if the actual effort is 300 N?

$$F = F_f + F_e,$$
$$F_f = F - F_e = 300\text{N} - 250\ \text{N} = 50\ \text{N}$$

c. What is the work output?

$$W_o = F_r d_r = (1000\ \text{N})(5.00\ \text{m}) = 5.00 \times 10^3\ \text{J}$$

d. What is the work input?

300 N

e. What is the mechanical advantage?

$$MA = \frac{d_e}{d_r} = \frac{20.0\ \text{m}}{5.00\ \text{m}} = 4.00$$

30. A mover's dolly is used to deliver a refrigerator up a ramp into a house. The refrigerator has a mass of 115 kg. The ramp is 2.10 m long and rises 0.850 m. The mover pulls the dolly with a force of 496 N up the ramp. The dolly and ramp constitute a machine.

a. What work does the mover do?

$$W_i = Fd = (496\ \text{N})(2.10\ \text{m}) = 1.04 \times 10^3\ \text{J}$$

b. What is the work done on the refrigerator by the machine?

d = height raised = 0.850 m

$$W_o = mgd = (115\ \text{kg})(9.80\ \text{m/s}^2)(0.850\ \text{m}) = 958\ \text{J}$$

c. What is the efficiency of the machine?

$$Efficiency = \frac{W_o}{W_i} \times 100\%$$
$$= \frac{(958\ \text{J})}{(1.04 \times 10^3\ \text{J})} \times 100\%$$
$$= 92.1\%$$

31. A pulley system lifts a 1345–N weight a distance of 0.975 m. Paul pulls the rope a distance of 3.90 m, exerting a force of 375 N.

a. What is the ideal mechanical advantage of the system?

$$IMA = \frac{d_e}{d_r} = \frac{(3.90\ \text{m})}{(0.975\ \text{m})} = 4.00$$

b. What is the mechanical advantage?

$$MA = \frac{F_r}{F_e} = \frac{(1345\ \text{N})}{(375\ \text{N})} = 3.59$$

c. How efficient is the system?

$$Efficiency = \frac{MA}{IMA} \times 100\%$$
$$= \frac{3.59}{4.00} \times 100\%$$
$$= 89.8\%$$

32. The ramp in Figure 10–18 is 18 m long and 4.5 m high.

a. What force parallel to the ramp ($F_{||}$) is required to slide a 25 kg box to the top of the ramp if friction is neglected?

$$W = F_w h = (25\ \text{kg})(9.8\ \text{m/s}^2)(4.5\ \text{m}) = 1.1 \times 10^3\ \text{J}$$
$$W = F_{||} d$$
$$F_{||} = \frac{W}{d} = \frac{(1.1 \times 10^3\ \text{J})}{18\ \text{m}} = 61\ \text{N}$$

b. What is the IMA of the ramp?

$$IMA = \frac{d_e}{d_r} = \frac{(18\ \text{m})}{(4.5\ \text{m})} = 4.0$$

Chapter Review Problems

c. What are the real *MA* and the efficiency of the ramp if a parallel force of 75 N is actually required?

$$MA = \frac{F_r}{F_e} = \frac{(25\text{ kg})(9.8\text{ m/s}^2)}{75\text{ N}} = 3.3$$

$$eff = \frac{MA}{IMA} \times 100\% = \frac{(3.3)}{(4.0)} \times 100\%$$

$$= 83\%$$

33. Because there is very little friction, the lever is an extremely efficient simple machine. Using a 90.0% efficient lever, what input work is required to lift an 18.0-kg mass through a distance of 0.50 m?

$$efficient = \frac{W_d}{W_i} \times 100\%$$

$$W_i = \frac{(W_d)(100\%)}{efficient} = \frac{(mgd)(100\%)}{(90.0\%)}$$

$$= \frac{(18.0\text{kg})(9.80\text{ m/s}^2)(0.50\text{m})(100\%)}{90.0\%}$$

$$= 98\text{ J}$$

34. What work is required to lift a 215-kg mass a distance of 5.65 m using a machine that is 72.5% efficient?

$$W_o = F_r d_r = (215\text{ kg})(9.80\text{ m/s}^2)(5.65\text{ m})$$
$$= 1.19 \times 10^4\text{ J}$$

$$\frac{W_o}{W_i} \times 100\% = 72.5\% = 0.725$$

$$W_i = \frac{W_o}{0.725} = \frac{(1.19 \times 10^4\text{ J})}{(0.725)} = 1.64 \times 10^4\text{ J}$$

35. A motor having an efficiency of 88% operates a crane having an efficiency of 42%. With what constant speed does the crane lift a 410-kg crate of machine parts if the power supplied to the motor is 5.5 kW?

Total efficiency = 88% × 42% = 37%

Useful power = 5.5 kW × 37% = 2.0 kW
= 2.0×10^3 W

$$P = \frac{W}{t} = \frac{Fd}{t} = F\left[\frac{d}{t}\right] = Fv$$

$$v = \frac{P}{F_w} = \frac{(2.0 \times 10^3\text{ W})}{(410\text{ kg})(9.8\text{ m/s}^2)} = 0.50\text{ m/s}$$

36. A complex machine is constructed by attaching the lever to the pulley system. Consider an ideal complex machine consisting of a lever with an *IMA* of 3.0 and a pulley system with an *IMA* of 2.0.

a. Show that the *IMA* of this complex machine is 6.0.

$$W_{ir} = W_o = W_{ir}' = W_o'$$
$$W_i = W_o$$
$$F_e d_e = F_r' d_r'$$

For the complex machine

$$IMA_c = \frac{d_e}{d_r'}$$

$$\frac{d_e}{d_r} = IMA;\ \frac{d_e'}{d_r} = IMA'$$

$$d_r = d_e'$$

$$\frac{d_e}{IMA} = d_r = d_e' = (IMA')(d_r')$$

$$d_e = (IMA)(IMA')(d_r')$$

$$\frac{d_e}{d_r'} = IMA_c = (IMA)(IMA')$$

$$= (3.0)(2.0) = 6.0$$

b. If the complex machine is 60.0% efficient, how much effort must be applied to the lever to lift a 540-N box?

$$\frac{F_r'}{F_e} = MA_c = \frac{(IMA) \times (eff)}{100\%}$$

$$\frac{F_r'}{F_e} = \frac{(6.0)(60.0\%)}{(100\%)} = 3.6$$

$$F_e = \frac{F_r'}{3.6} = \frac{540\text{ N}}{3.6} = 150\text{ N}$$

c. If you move the effort side of the lever 12.0 cm, how far is the box lifted?

$$\frac{d_e}{d_r} = IMA_c$$

$$d_r' = \frac{d_e}{IMA} = \frac{12.0\text{ cm}}{6.0} = 2.0\text{ cm}$$

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